A Test of Computer-Assisted Matching using the North Pacific Humpback Whale (*Megaptera novaeangliae*) Tail Flukes Photograph Collection

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ABSTRACT

Testing was conducted of a computer-assisted system for matching humpback whale tail flukes photographs. Tests of the system with a database of approximately 12,000 photographs found no differences in match success between matching by computer and matching by comparing smaller catalogs ranging in size from 200-400 photographs. Tests of the system with a database of approximately 25,000 photographs showed that, on average, the first match was found after examining approximately 130 photographs if the photograph quality was excellent or good, and after examining approximately 220 photographs if the photograph quality was poor Match success did not appear to be strongly related to whether the tail flukes had especially distinctive markings or pigment patterns (recognition quality). An advantage of computer-assisted matching is the ability to compare new photographs to the entire North Pacific collection, where no bias is introduced based on expectation of resightings within or between specific areas, or based on expectation of behavioral role (*e.g.*, matching "known" females to "known" females)

Key words: humpback whale, *Megaptera novaeangliae,* photo-identification individual identification, matching, computer-assisted matching, tail flukes, photographic quality, recognition quality, distinctiveness

In the mid-1960s, researchers began to photograph individual marine mammals, using photographic identification techniques to identify individuals on the basis of natural markings Over time, researchers began to develop catalogs of individuals as the individual marine mammals were sighted in different years and areas (Hammond *et al.* 1990). As the number of photographs has increased, so has the need for computer assistance to help with the collation and integration of the large collections. Starting in the mid-1980s, computer-assisted systems began to be developed to aid in the identification of individual marine mammals (Hiby and Lovell 1990 and Mizroch *et al.* 1990) The systems developed by Hiby and Lovell use a scanned image and a 3-dimensional computer model to interpret the photograph and to develop an identification algorithm Their systems are considered semi-automated because the computer system measures some of the photograph's characteristics independent of the system operator The system developed by Mizroch and colleagues is categorical and requires that identification photographs be classified visually (by a trained observer) This system is based on a categorization scheme of natural marks and scars, and data related to each photograph are entered into a computer database The system operator controls all of the matching information and uses a computer to query the database for possible matching choices

The National Marine Mammal Laboratory (NMML) has been developing and curating a collection of humpback whale tail flukes photographs taken in North Pacific waters since 1985 The collection of North Pacific humpback whale tail flukes photographs has grown from about 750 photographs in 1986 to more than 25,000

photographs in 1999, representing contributions from over 18 research groups from all regions in the North Pacific (Table 1). Unique NMML identification numbers (NMMLID) are assigned only when there are at least 2 photographs of a particular individual whale in the database. As of April 1999, 3,137 unique NMMLID numbers had been assigned and 12,649 tail flukes photographs had been assigned a NMMLID. There were 12,559 tail flukes photographs that have not yet been assigned a NMMLID Overall, the 25,208 tail flukes photographs evaluated here may represent the sightings and resightings of no more than 6,000 individual whales.

When conducting certain types of numerical studies using photo-identification data (*e.g.*, capture-recapture analyses), it is important to segregate the photographic data strictly on photographic quality only (Hammond 1986; Hammond *et al.* 1990; Mizroch *et al.* 1990). Photographs in the database are given two different ratings: one based on photographic quality (focus, angle, distance), and the other based on recognition quality (distinctive pattern, marks or scars) (see Mizroch *et al.* 1990 for more details) The analysis conducted here stratified the photographs by three levels of photographic quality (hereafter referred to as photo quality), examples of which are shown in Figure 1 Matching was conducted using the system described in Mizroch *et al.* (1990), except that the patterns in use today (Fig. 2) have been simplified and improved. The tail flukes map (Fig. 3) has not been modified.

Tests of the NMML system (*i.e.*, stratified by recognition quality) were first presented in Mizroch *et al.* 1990), when the database contained 9,353 photographs Here, we present test results for the NMML database when it contained 12,000

photographs (using *ad hoc* tests conducted from 1991-1995), and recent tests, with the database at its current size of over 25,000 photographs.

METHODS

Categorizing whale tail flukes

Humpback whale tail flukes have black and white pigment patterns that can be categorized (Fig. 2). For each photograph, a selection of patterns that most closely resembled the tail flukes was chosen In general, the user selected between one and six patterns for each photo being matched, depending on what characteristics were visible on the photograph to be matched. In addition to selecting patterns, the user evaluated locations of natural markings, scars, or other unique marks on the tail flukes (see Fig. 3), and selected any or all sectors that contained the markings (*e.g.*, a distinctive line in Sector 5 and an open circle in Sector 6). If the mark extended across sectors, it was described in both If it is not clear which sector to select, a mark was described as being in one or the other.

For each photograph matched, after the input criteria were selected, the matching program queried the database and brought up a subset of all photographs in the database that matched the input criteria and displayed each photograph sequentially on a TV monitor. The operator compared each photograph on the TV monitor to the photograph to be matched and determined if there was a match or not. In cases where the photograph on the TV monitor was difficult to interpret, the operator pulled the original photograph from the files to evaluate.

Testing with 12,000 photographs

As part of data preparation for analyses of calf mortality and birth interval, humpback whale researchers in the North Pacific conducted an *ad hoc* matching test in the early 1990s. Researchers from Glacier Bay National Park and Preserve (Gabriele) University of Alaska (Straley) and North Gulf Oceanic Society (von Ziegesar), working independently of each other and NMML staff (primarily Wolman), compared their catalogs to a catalog of known females prepared during a workshop on calf mortality (called here the "calf mortality" catalog, containing 352 individual whales). Their catalogs, which represented Alaska areas including Glacier Bay, portions of southeastern Alaska, and Prince William Sound, ranged in size from about 200 individuals to about 400 individuals. The tail flukes photograph collection at the NMML at the time of the matching exercise numbered about 12,000 photographs including photographs from all regions in the North Pacific. The matching success of computer-assisted matching at the NMML was compared to matching success of each individual researcher visually inspecting their own hard-copy catalogs (Mizroch, S. A. Report of the workshops on the estimation of calf mortality in North Pacific humpback whales To be submitted as a NOAA Tech Memo. 38pp., Unpublished data).

Testing with 25,000 photographs

A random selection of approximately 0.5% of the database (125 photographs) was made, stratified by photo quality codes (Table 2) Based on the stratification, there were 15 photo quality 1 (excellent) photos, 80 photo quality 2 (good or moderate) photos and 30 photo quality 3 (poor) photos selected. The draw from the database was

independent of recognition quality and of whether the animal had been matched previously.

At the time of the matching exercise, we did not know whether the photographs had been matched previously. For each photograph selected, the computer-assisted matching program was used to match each photograph to the entire collection, and matching was halted either when the first match was found, or when 5% of the database (1,250) photographs had been examined. If the photograph was of a well-known animal, the match criteria used for this exercise were based strictly on the detail showing on the photograph drawn randomly, rather than on other known marks or scars that the individual may have accumulated over time.

RESULTS

Testing with 12,000 photographs

The Glacier Bay catalog numbered about 200 individual whales at the time of the matching exercise. Ten of the 12 matches between the "calf mortality" catalog and the Glacier Bay catalog were found independently by both Gabriele and Straley and by NMML staff. Gabriele and Straley found one match that NMML staff missed and NMML staff found one match that Gabriele and Straley missed (Table 3)

The southeastern Alaska catalog numbered about 400 individual whales at the time of the matching exercise Both Straley and NMML staff found 19 of the 21 matches between the "calf mortality" catalog and the southeastern Alaska catalog

independently. Straley found one match that was missed by NMML staff, and NMML staff found one match that was missed by Straley (Table 3)

The Prince William Sound catalog numbered about 200 individual whales at the time of the matching exercise. Both von Ziegesar and NMML staff found six of the 10 matches found between the "calf mortality" catalog and the Prince William Sound catalog independently. von Ziegesar found three matches that NMML staff missed and NMML staff found one that von Ziegesar missed. The number of matches missed from this set was somewhat larger than the others (Table 3). For at least one of the matches made by von Ziegesar and missed by NMML staff, the photo quality was poor, and the match was based mainly on trailing edge shape and detail, and not the marks, scars and pigment patterns that were apparent on a good quality photograph of the tail.

Overall, 38 of the 43 total matches found (88%) were made using the computer-assisted system There was no significant difference in matches found for each area (Chi-square = 4.37, $P = 0.11$)

Testing with 25,000 photographs

Photo quality 1 Of the 15 photo quality 1 photographs, matches were found for all 15 photographs. In 10 cases, the first match was found in the top 0.0027 of the database (fewer than 70 photographs evaluated). In all 15 cases, the first match was found in the top 0.031 of the database (Table 4, Fig. 4). On average, the first match was found in the top 0.005 of the database (approximately 130 photographs) (SD = 0.0079).

Examples of two of the photo quality 1 matches, including the pattern and marks selections are presented in Figures 5 and 6. Figure 5 shows a match that was found after making one change in selection criteria and evaluating 69 photographs. Figure 6 shows a whale that had no apparent marks, and the match was found after evaluating 793 photographs.

Photo quality 2: Of the 80 photo quality 2 photographs, matches were found for 48 photographs. Of these 48 photographs, in 30 cases the first match was found in the top 0.0027 of the database (70 or fewer photographs evaluated) (Table 5, Figure 4) On average, the first match was found in the top 0.005 of the database (approximately 130 photographs) (SD = 0.0072).

In only three cases, known matches of photo quality 2 photos were missed, due to the following reasons (Fig. 7)

For photograph 5889, the flecked markings (speckled or streaked pigment markings which were present in both Sectors 5 and 8) did not appear to be present in Sector 5 on the photograph missed in the database, so the matching photograph was not selected in any of the matching selections

For photograph 50363, the matching photograph lacked any detail, and would have been found only after looking at more than 1,250 photographs, the arbitrary cut-off point for this exercise, because of where it was on the list of photos selected from the database

For photograph 61147, the distinctive circle in Sector 6 was present but not coded as such on the photograph in the database, so the matching photograph was not selected in any of the matching selections

Examples of two of the photo quality 2 matches, including the pattern and mark selections, are presented in Figures 8 and 9. Figure 8 shows a match that was found after evaluating 42 photographs. Figure 9 shows a match that was found after making two changes in selection criteria and evaluating 764 photographs.

Photo quality 3: Of the 30 photo quality 3 photographs, matches were found for 16 photographs. Of these 16 photographs, in 9 cases the first match was found in the top 0.0034 of the database (85 or fewer photographs evaluated) (Table 6, Fig. 4). On average, the first match was found in the top 0.0088 of the database (approximately 220 photographs) (SD = 0.0124).

In only two cases, known matches of photo quality 3 photographs were missed due to the following reasons (Fig. 7):

For photograph 9774, only part of one tail fluke was showing, and there were very few distinguishing marks present

For photograph 34697, the photo quality was so poor that the match could only be confirmed by the researcher who took the photo

Examples of two of the photo quality 3 matches, including the pattern and marks selections, are presented in Figures 10 and 11 Figure 10 shows a match which was

found after making two changes in selection criteria and evaluating 102 photographs. Figure 11 shows a match which was found after making one change in selection criteria and evaluating 1,069 photographs.

Results for photos of qualities 1 or 2 were surprisingly similar. As might be expected, more photographs had to be evaluated to find matches from photo quality 3 photographs. In Figure 12, results are presented independent of photo quality, sorted by match success, with recognition quality plotted for each photograph. Recognition quality is based on the presence of distinctive markings or pigmentation, which should affect one's ability to recognize the individual even if photo quality is very poor. There did not appear to be a trend in recognition quality with respect to known matches that were missed. Also, there did not appear to be a trend with respect to the photographs as yet unmatched (Fig. 13).

Overall, matches were found for 79 of the 125 photographs, and on average, the first match was found in the top 0.0060 of the database (approximately 150 photographs) (SD = 0.0087).

Discussion

Testing with 12,000 photographs

This exercise confirmed that computer-assisted matching was an effective matching tool, especially considering that NMML staff was comparing the "calf mortality" catalog to a collection of over 12,000 photographs, not to individual catalogs ranging in size from 200-400 photographs.

Testing with 25,000 photographs

Figure 12 indicates no trend in match results with respect to recognition quality which may mean that even the less distinctive tail flukes photographs have enough detail so matches can be found.

Of the 125 photographs selected at the time the matching exercise began, only 55 had been previously matched (*i.e.*, assigned a NMMLID). New matches were found for 29 of the photographs and 41 remain without known matches. Overall, only five known matches were missed.

An advantage of computer-assisted matching is the ability to compare new photographs to the entire North Pacific collection and the potential to find matches to whales photographed in other regions. No bias is introduced based on expectation of resightings within or between specific summer or winter grounds. Another advantage in using computer-assisted matching is that by matching to the entire collection, no bias is introduced based on expectation of behavioral role (*e.g.*, matching "known" females to "known" females).

At this time, the NMML computer matching system is able to match effectively with a database of over 25,000 photographs to choose from. The computer-assisted system has continued to be an efficient matching system for such a large number of photographs because the matching criteria are always controlled by a human operator and because database performance is not constrained by size. Data entry is fast (between 100-200 photographs entered per day). Image capture and retrieval is fast, with the capability of capturing 5,000 images per day on a videodisc that holds 54,000 images. Image retrieval time ranges from a fraction of a second to a couple of seconds, depending on the distance between images on the videodisc.

Conclusions

Since the NMML system has been in use, there has been the desire to develop computer-assisted systems that are more "automated" The NMML system takes advantage of the human brain's ability to instantly rotate, adjust, compensate and recognize similar images. Computer technology cannot yet compete with the image processing power of the human brain, and it is not so advanced that a completely automated system is possible. Both the categorical systems used here and the other systems developed by Hiby take some operator training and intervention.

There are new systems being developed for identifying individual Alaska harbor seals that should provide a direct comparison of categorical versus semi-automated systems. Future sample sizes will likely be large enough to compare the two approaches with rigor.

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In addition, we thank the many research groups whose photographs are part of the research collection (see Table 1 including those groups who allowed us to use their photos as examples in this paper (photo credits in parentheses), including Cascadia Research Collective (Fig. 1: photo 45598; Fig 7: photos 5889, 5924, 9774 and 45364) Center for Whale Research (Fig. 7: photos 5889 and 5924), Center for Whale Studies (Fig photos 23141 and 23407; Fig. 7: photos 50363 and 50364; Fig. 8: photo 24291 Glacier Bay National Park and Preserve (Fig. 8: photo 18502), Hawaii Whale Research Foundation (Fig.1: photos 50236 and 60328; Fig. 7: 61147 and 61148) Straley Investigations (Fig. 9: photo 5842), J. Jacobsen (Fig. 5: photo 14262; Fig. 10: photos 2658 and 2722), Moss Landing Marine Labs (Fig. 7: photo 34540 and 34697 Fig. 8: photos 44126), National Marine Mammal Laboratory (Fig. 6: photo 25436) NMFS, Alaska Region (Fig. 9: photo 25013), Pacific Whale Foundation (Fig. 11: photo 3539), Universidad Autonoma de Mexico (Fig. 5: photos 2053 and 14262; Fig. 10 photos 2658 and 2722), West Coast Whale Research Foundation (Fig. 1: photo 10465 and Fig photo 10642)

LITERATURE CITED

Hammond, P. 1986. Estimating the size of naturally marked whale populations using capture-recapture techniques. Reports of the International Whaling Commission (Special Issue 8):253-282

Hammond, P., S. A. Mizroch and G. Donovan. 1990. Report of the workshop on individual recognition and the estimation of cetacean population parameters. Reports of the International Whaling Commission (Special Issue 12):3-40.

Hiby, A. R. and P. Lovell. 1990. Computer aided matching of natural markings: a prototype system for gray seals. Reports of the International Whaling Commission (Special Issue 12):57-61.

Mizroch, S. A., J. A. Beard and M. Lynde. 1990. Computer assisted photo-identification of humpback whales. Reports of the International Whaling Commission (Special Issue 12):63-70.

Rugh, D. J., J. E. Zeh, W. R. Koski, L. S. Baraff, G. W. Miller and K. E. W. Shelden. 1998. An improved system for scoring photo quality and whale identifiability in aerial photographs of bowhead whales. Reports of the International Whaling Commission 48:510-512.

Table 1. Major contributing research groups and primary contact people.

Research group	Primary contact
Center for Coastal Studies	D. Mattila
Cascadia Research Collective	J. Calambokidis, G. Steiger
Center for Whale Research	K. Balcomb, D. Claridge
Center for Whale Studies	D. Glockner-Ferrari, M. Ferrari
Glacier Bay National Park and Preserve	C. Gabriele
Hawaii Whale Research Foundation	D. Salden
J. Straley Investigations	J. Straley
Kewalo Basin Marine Mammal Laboratory	L. Herman, A. Craig
Moss Landing Marine Labs	S. Cerchio
North Gulf Oceanic Society	O. von Ziegesar, C. Matkin
National Marine Mammal Laboratory	S. Mizroch
Okinawa Expo Aquarium	S. Uchida, N. Higashi
Pacific Biological Station	G. Ellis
Pacific Whale Foundation	R. Baird
SeaSearch	C. and S. Jurasz
Univ. Autonoma de Baja Calif. Sur	J. Urban
Univ. Nacional Autonoma de Mexico	M. Salinas, J. Jacobsen
West Coast Whale Research Foundation	J. Darling, E. Mathews, D. McSweeney, K. Mori

Table 2. Number of photographs in the database stratified by photo quality (see Figure 1) and recognition quality

	Recognition quality						
Photo quality	1	2	3	0	Total	1%	0.5%
1 (excellent)	2742	420	40		3202	30	15
2 (good)	7255	6627	1642		15524	160	80
3 (poor)	1032	2152	2434	84	5702	60	30
Total	11029	9199	4116	84	24428	250	125

Category 0 means that the recognition quality cannot be evaluated due to poor photo quality

Table 3. Comparisons of computer-assisted matches and matches from each Alaska research group, matching the "calf mortality" catalog to each independent collection. The "calf mortality" catalog included photographs of approximately 350 individual whales, and the NMML database contained approximately 12,000 tail fluke photographs at the time of this matching exercise.

Catalog	Approximate sample size	Observed by both NMML and research group	Total number of matches found
Glacier Bay	200	10	12
southeastern Alaska	400	19	21
Prince William Sound	200	6	10

Table 4. Photo quality 1 results, including numbers of photographs looked at and origin of each photo

Accession number	Photo quality	Recognition quality	Number of photographs looked at until first match was found	Proportion of the database examined	Geographic origin of photo
10087	1	1	4	0.000158648	Hawaii
848	1	1	11	0.000436283	Hawaii
28207	1	1	12	0.000475945	Hawaii
23827	1	1	17	0.000674255	Hawaii
28892	1	1	45	0.001784794	Hawaii
29233	1	1	56	0.002221076	Hawaii
2810	1	1	58	0.002300401	Mexico
23407	1	1	61	0.002419387	Hawaii
5330	1	1	65	0.002578035	Alaska
2053	1	1	69	0.002736683	Mexico
45598	1	1	107	0.004243842	California
9115	1	1	153	0.006068298	California
28841	1	1	227	0.009003292	Hawaii
9768	1	2	288	0.011422679	California
25436	1	2	793	0.031452029	Alaska
		Average (Standard Deviation)	131.0667	0.005198 (0.007949	

Table 5. Photo quality 2 results, including numbers of photographs looked at and origin of each photo

	Photo quality	Recognition quality	Number of photographs looked at until first match was found	Proportion of the database examined	Geographic origin of photo
29213	2		1	3.96621E-05	Hawaii
135	2	2	2	7.93242E-05	Alaska
37195	2		3	0.000118986	Alaska
3164	2	1	5	0.00019831	Hawaii
40317	2	2	5	0.00019831	Hawaii
6832	2	1	7	0.000277635	Alaska
5507	2	2	7	0.000277635	Alaska
3007	2	1	9	0.000356959	Hawaii
39389	2	1	9	0.000356959	Hawaii
36384	2	1	12	0.000475945	Alaska
28227	2	1	16	0.000634593	Hawaii
29724	2	2	16	0.000634593	Hawaii
39914	2	2	20	0.000793242	Hawaii
22558	2	1	24	0.00095189	Hawaii
23683	2	2	25	0.000991552	Hawaii
116	2	1	26	0.001031214	Alaska
3298	2	1	28	0.001110538	Hawaii
39138	2	1	28	0.001110538	Hawaii
37658	2	3	28	0.001110538	Alaska
60184	2	2	38	0.001507159	Hawaii
22749	2		39	0.001546821	Hawaii
34584	2	1	42	0.001665807	Hawaii
24291	2	2	42	0.001665807	Hawaii
36179	2	2	61	0.002419387	Alaska
8112	2	1	63	0.002498711	Hawaii
16240	2	1	66	0.002617697	Mexico
75991	2	1	67	0.002657359	Alaska
38357	2	1	69	0.002736683	Alaska
22377	2	1	70	0.002776346	Hawaii
23914	2	2	101	0.00400587	Hawaii
1585	2		108	0.004283505	Hawaii
5502	2	3	118	0.004680125	Alaska

Accession number	Photo quality	Recognition quality	Number of photographs looked at until first match was found	Proportion of the database examined	Geographic origin of photo
114	2	2	143	0.005671677	Alaska
28574	2	1	182	0.007218498	Hawaii
23945	2	3	191	0.007575457	Hawaii
39955	2	2	208	0.008249712	Hawaii
1194	2	1	223	0.008844644	Hawaii
50236	2	1	228	0.009042954	Hawaii
7535	2	1	247	0.009796534	Alaska
39102	2	1	249	0.009875858	Hawaii
23980	2	2	272	0.010788086	Hawaii
25855	2	2	275	0.010907072	Alaska
38704	2	2	292	0.011581327	Alaska
44091	2	2	302	0.011977948	Hawaii
18044	2	2	346	0.013723079	Alaska
9078	2	1	375	0.01487328	California
5842	2	1	764	0.030301828	Alaska
12102	2	2	897	0.035576885	Alaska
1547	2	2	No match	0.05	Hawaii
2003	2	2	No match	0.05	Mexico
2935	2	2	No match	0.05	Mexico
3081	2	1	No match	0.05	Hawaii
3545	2	3	No match	0.05	Hawaii
5380	2	2	No match	0.05	Alaska
5889	2	1	No match	0.05	California
10465	2	1	No match	0.05	Hawaii
10592	2	1	No match	0.05	Hawaii
10848	2	2	No match	0.05	Hawaii
10973	2	1	No match	0.05	Hawaii
11171	2	2	No match	0.05	Hawaii
14802	2	3	No match	0.05	Mexico
16300	2	1	No match	0.05	Mexico
16327	2	1	No match	0.05	Mexico
17430	2	1	No match	0.05	Alaska
23506	2	1	No match	0.05	Hawaii
27102	2	2	No match	0.05	Hawaii

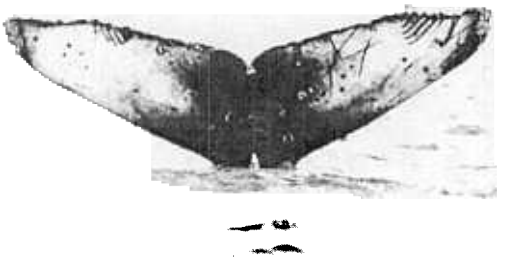
Accession number	Photo quality	Recognition quality	Number of photographs looked at until first match was found	Proportion of the database examined	Geographic origin of photo
30394	2	2	No match	0.05	Japan
37170	2	3	No match	0.05	Alaska
37410	2	2	No match	0.05	Alaska
39090	2	3	No match	0.05	Hawaii
40418	2	2	No match	0.05	Hawaii
44567	2	2	No match	0.05	Hawaii
45217	2	3	No match	0.05	California
45651	2	3	No match	0.05	Oregon
50363	2	2	No match	0.05	Hawaii
50400	2	2	No match	0.05	Hawaii
60328	2	3	No match	0.05	Hawaii
60620	2	2	No match	0.05	Hawaii
61147	2	2	No match	0.05	Hawaii
99914	2	2	No match	0.05	Colombia
		Average (Standard Deviation)	132.2708	0.005246 (0.007242)	

Table 6. Photo quality 3 results, including numbers of photographs looked at and origin of each photo

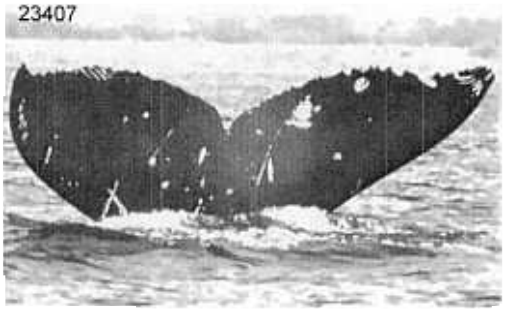
Accession number	Photo quality	Recognition quality	Number of photographs looked at until first match was found	Proportion of the database examined	Geographic origin of photo
29288	3	2	1	3.96621E-05	Hawaii
34937	3	3	2	7.93242E-05	Hawaii
25519	3	3	3	0.000118986	Alaska
80029	3	2	9	0.000356959	Mexico
70044	3	2	12	0.000475945	Mexico
174	3	2	16	0.000634593	Hawaii
75263	3	0	17	0.000674255	Alaska
5755	3	0	19	0.00075358	Mexico
22809	3	3	85	0.003371277	Hawaii
2658	3		101	0.00400587	Mexico
22281	3		194	0.007694443	Hawaii
9418	3	2	416	0.016499425	California
23141	3	2	473	0.018760163	Hawaii
37034	3	1	491	0.019474081	Alaska
3434	3	3	661	0.026216634	Hawaii
3539	3	2	1069	0.042398763	Hawaii
1783	3		No match	0.05	Hawaii
3485	3	2	No match	0.05	Hawaii
4366	3	3	No match	0.05	Hawaii
9774	3	2	No match	0.05	California
10725	3	2	No match	0.05	Hawaii
22031	3	2	No match	0.05	Hawaii
23785	3	3	No match	0.05	Hawaii
28185	3	3	No match	0.05	Hawaii
29292	3	3	No match	0.05	Hawaii
34549	3	2	No match	0.05	Hawaii
34697	3	3	No match	0.05	Hawaii
37237	3	3	No match	0.05	Alaska
46410	3	3	No match	0.05	California
50102	3	2	No match	0.05	Hawaii
		Average (Standard Deviation)	223.0625	0.008847 (0.012448)	

Figure 1. Examples of photographs showing photo quality codes

45598



23407



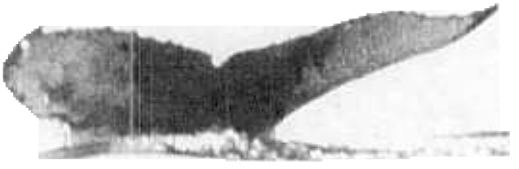
Excellent: Photo quality 1

50236

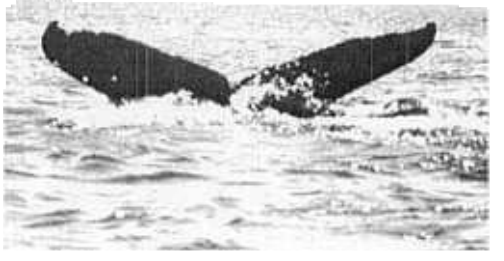
10465

Good or Moderate: Photo quality 2

60328



23141



Poor: Photo quality 3

Figure 2. Tail flukes patterns, slightly modified from the patterns presented in Mizroch *et al.* (1990).

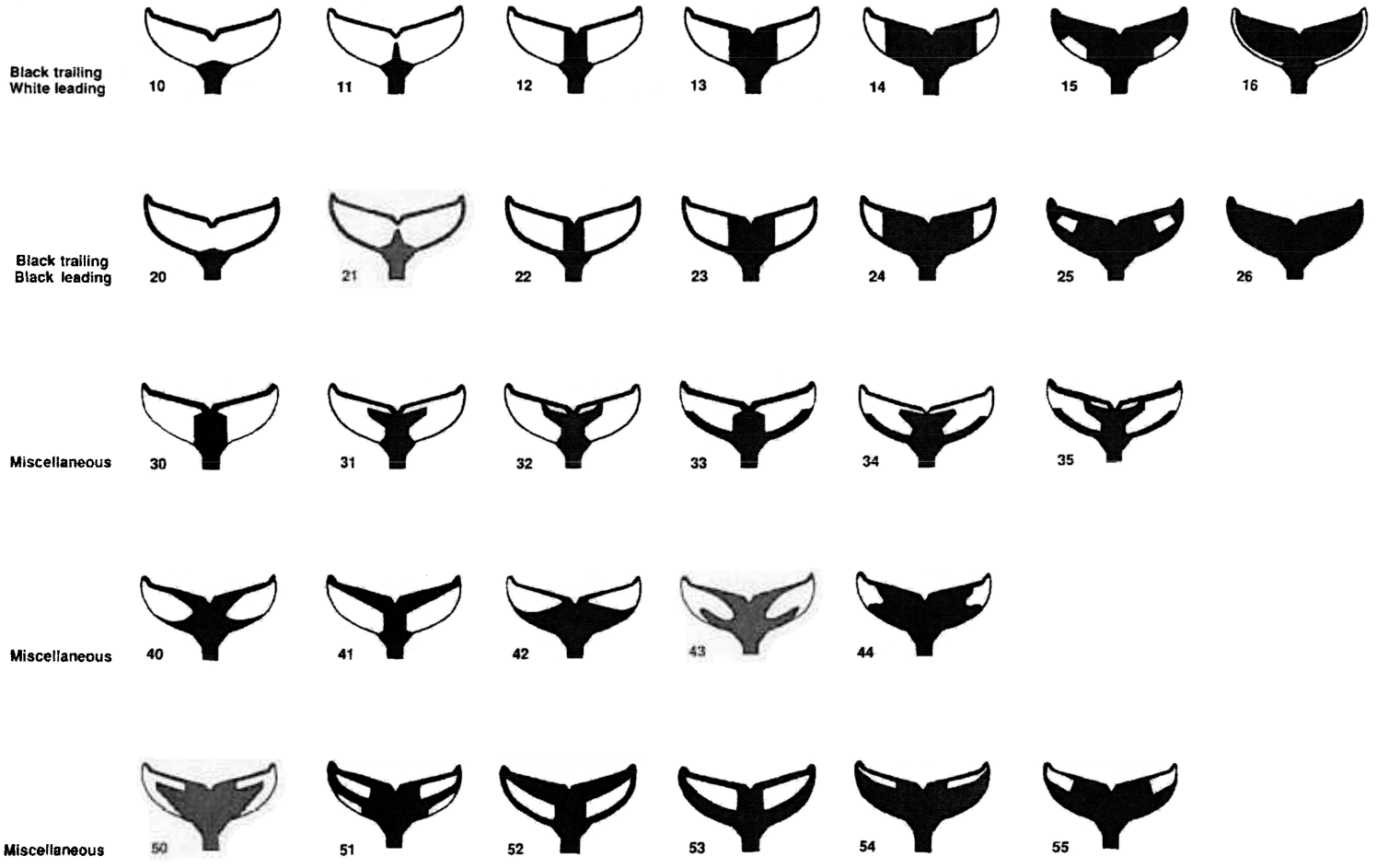
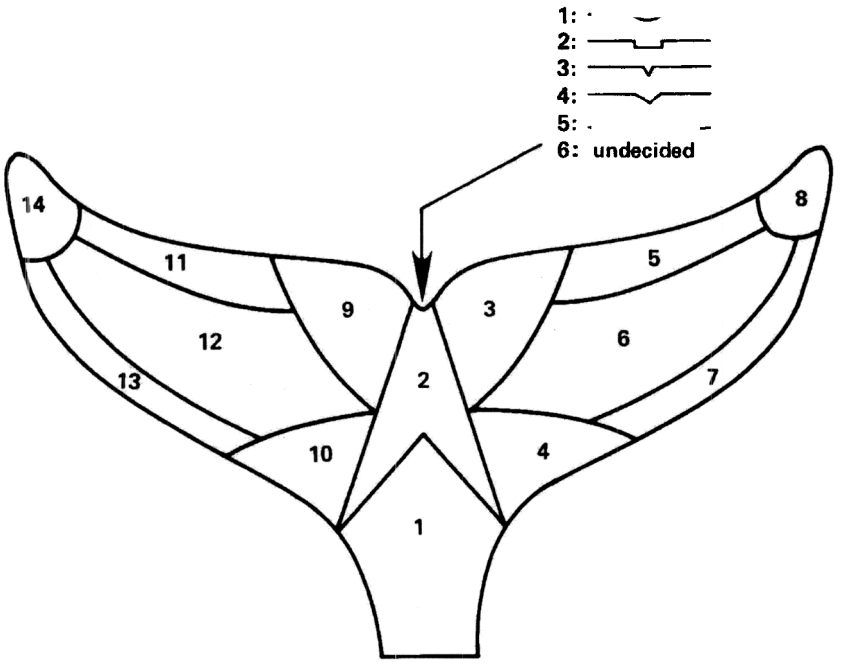


Figure 3. Tail flukes map



Mark Codes:

C: Open circle, black
c: Open circle, white

F: Flecks or mottled

H: Hole

L: Line, black
l: Line, white

M: Sector missing from animal

N: Notch, nick or bite

R: Rakes (predator bites), black
r: Rakes, white

S: Spot, black
s: Spot, white

X: Distinctive mark of any kind (used with another mark code)

*** Sector underwater, out of frame, or at a bad angle**

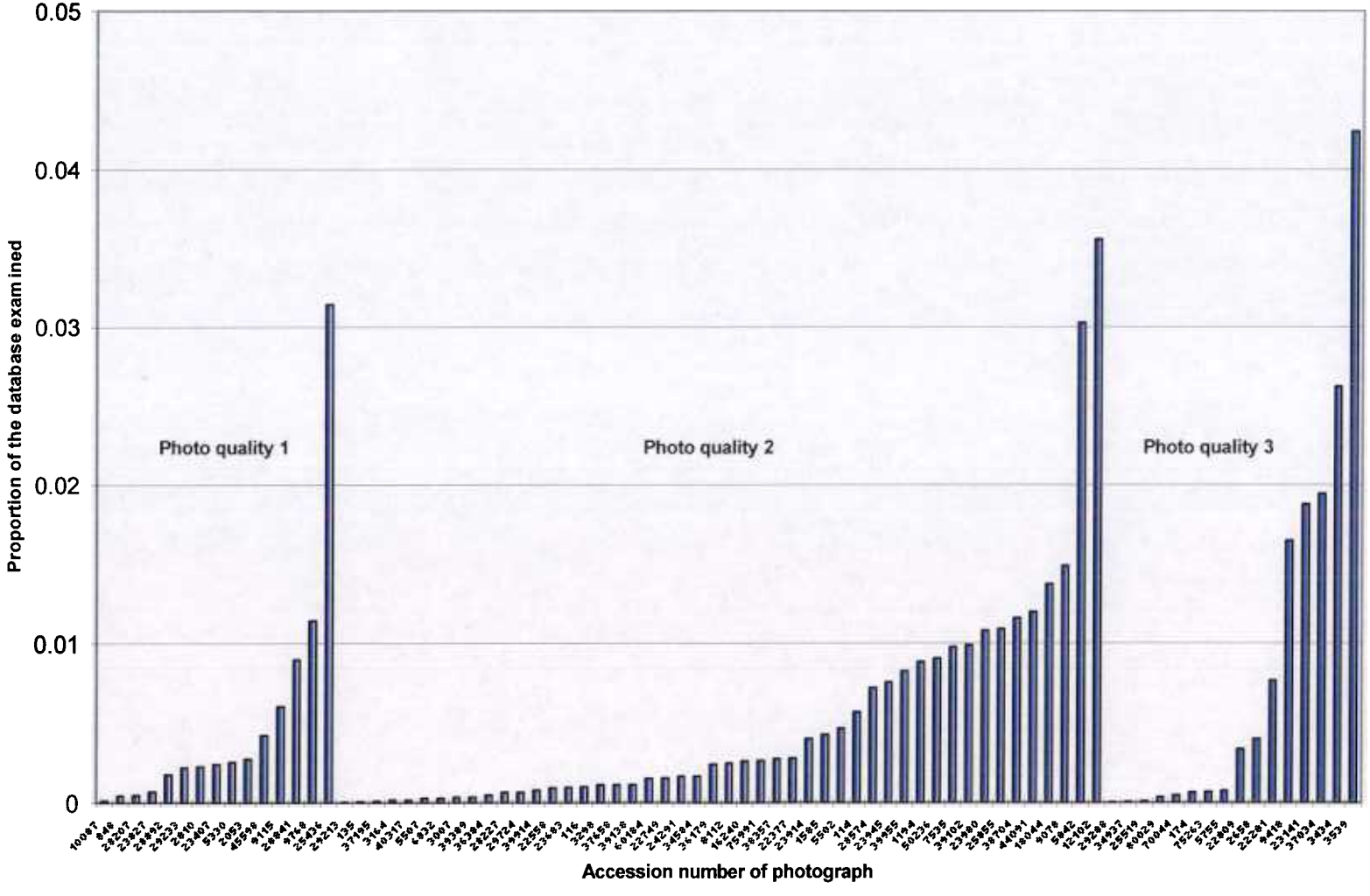
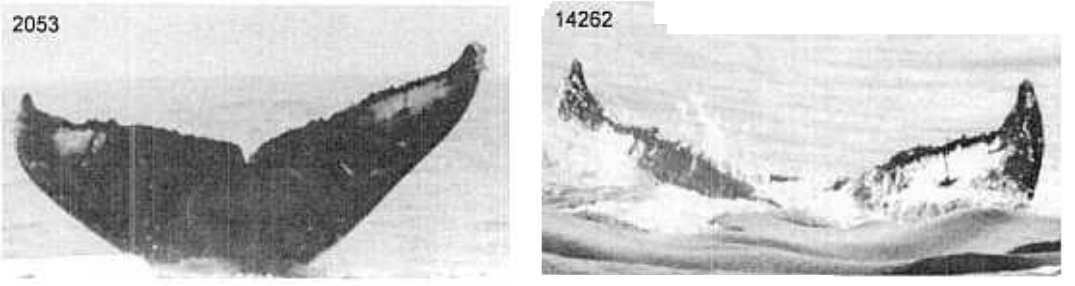


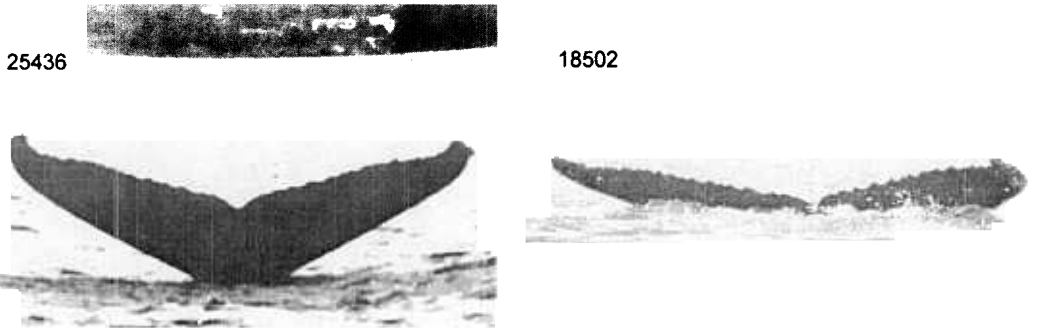
Figure 4. Test results for photographs where matches were found, photo qualities 1-3

Figure 5. Example of the evaluation of photo accession number 2053, coded as photo quality 1.



	Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
	54, 55	XL in 11	57
	54, 55	L in 5 and 11	12
Total			69

Figure 6. Example of the evaluation of photo accession number 25436, coded as photo quality 1.



	Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
	26	none	793
Total			

Figure 7. Examples of photographs where matches were missed, coded as photo quality 2 and 3.

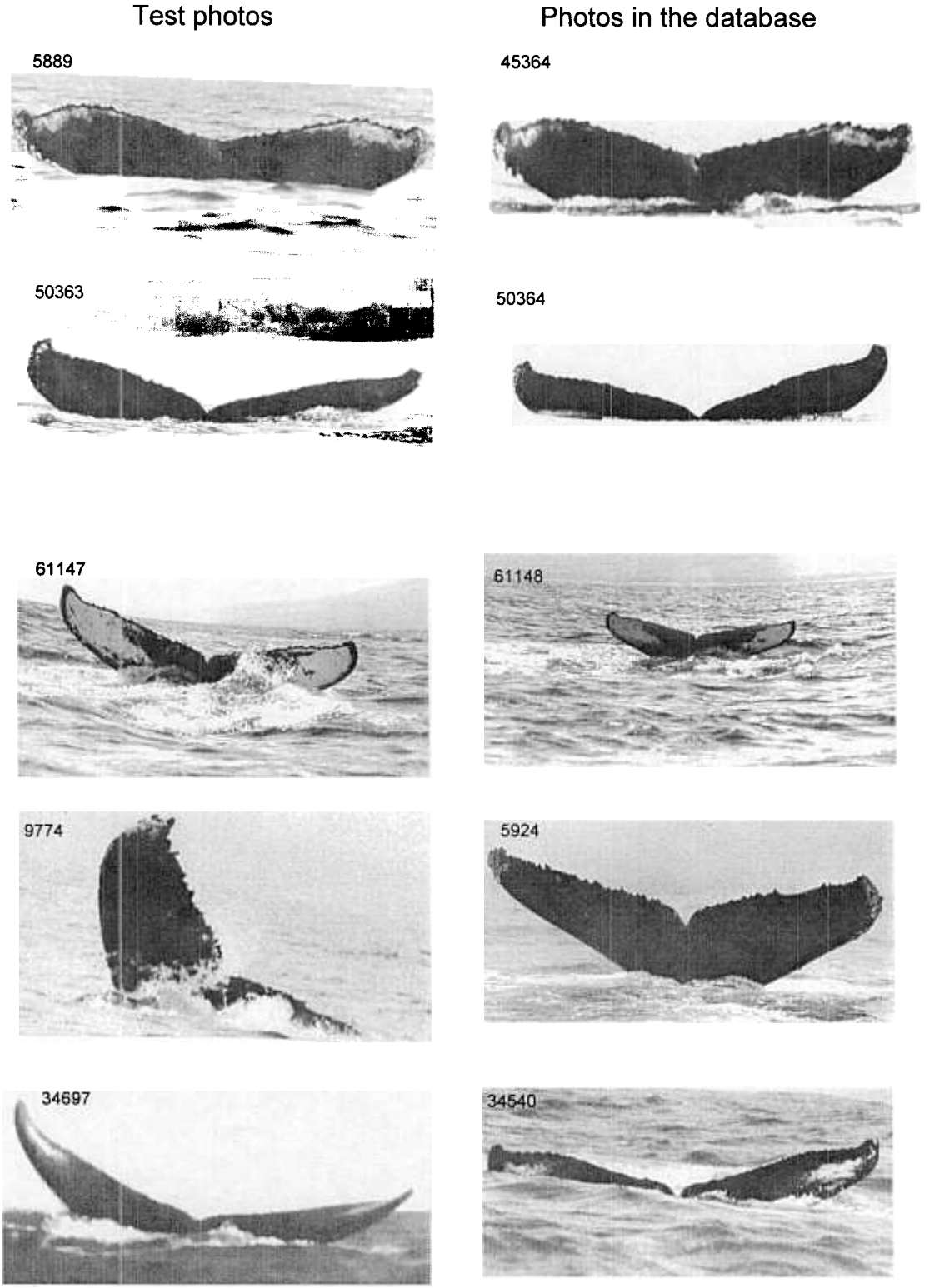
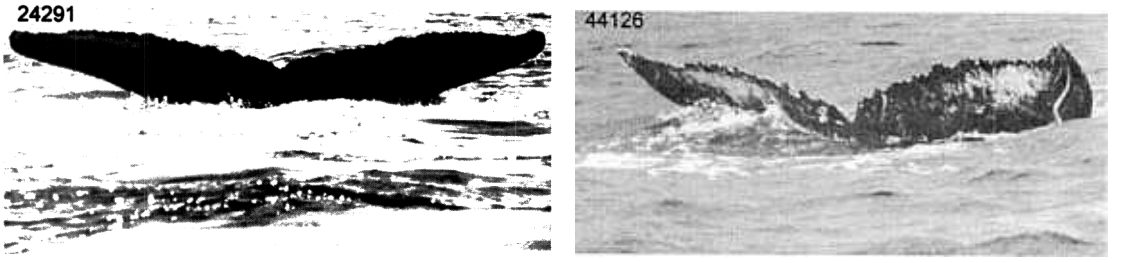
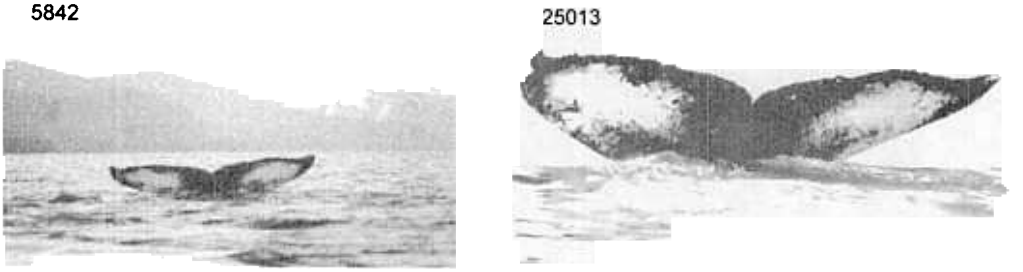


Figure 8. Example of the evaluation of photo accession number 24291, coded as photo quality 2.



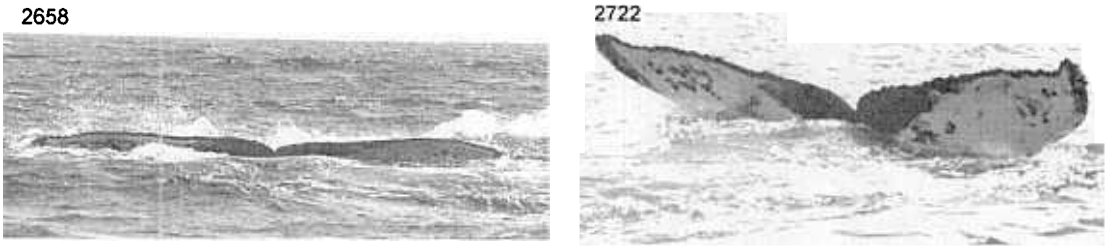
	Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
	53, 54, 55	I in 9 and 3	42
Total			42

Figure 9. Example of the evaluation of photo accession number 5842, coded as photo quality 2.



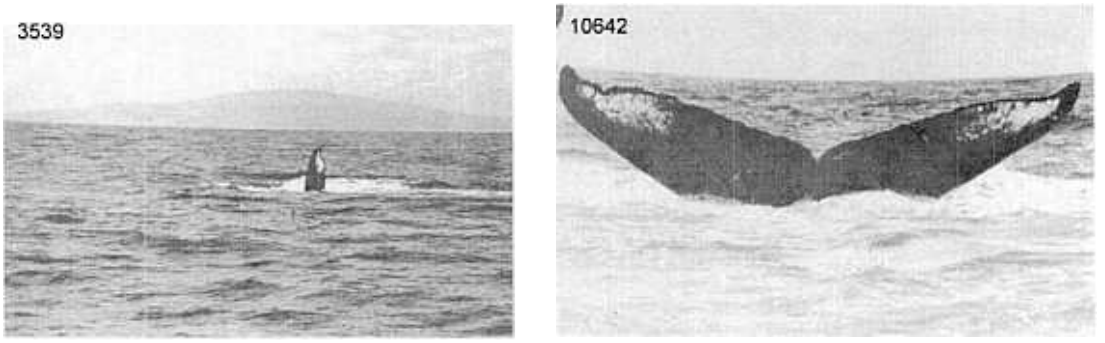
	Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
	13, 40, 41, 43	X in 11 or 13	170
	13, 40, 41, 43	L in 5 and S in 13	344
	13, 40, 41, 43	F in 6	250
Total			764

Figure 10. Example of the evaluation of photo accession number 2658, coded as photo quality 3.



	Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
	12, 13, 40	XS in 11	74
	12, 13, 40	XC in 11	4
	12, 13, 40	XC or XS in 12	23
Total			101

Figure 11. Example of the evaluation of photo accession number 3539, coded as photo quality 3.



	Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
	55	L in 11 and 12	611
	55	L in 14	458
Total			1,069

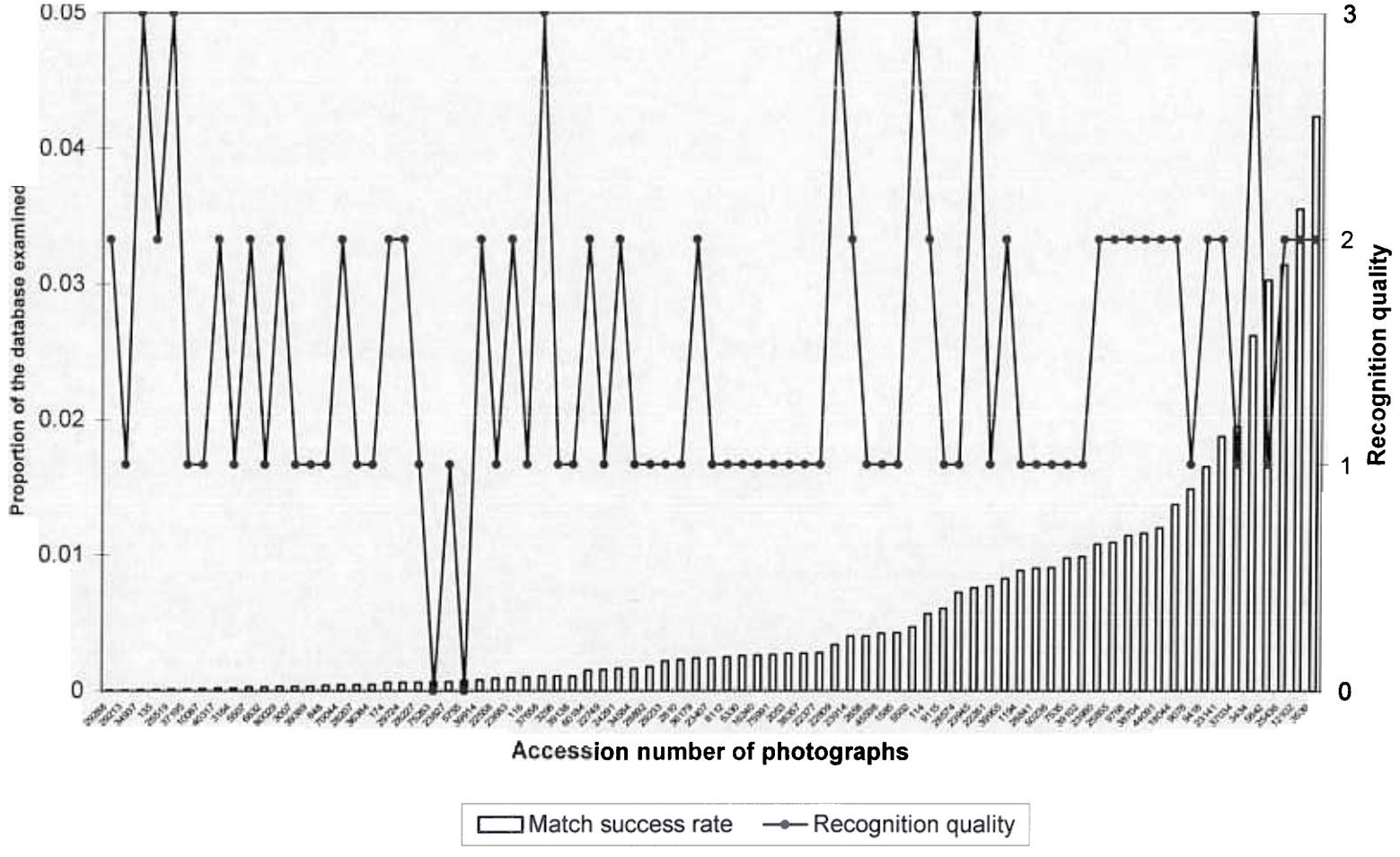


Figure 12. Recognition quality (RQ) versus proportion of the database evaluated for each photograph. RQ 0: photo cannot be evaluated for recognition quality; RQ 1: Excellent; RQ2: Good or moderate; RQ3: Poor.

Figure 13 Recognition quality of photographs where matches were not found. The first 5 bars (no color) represent photographs for which known matches were missed (see Figure 7). Matches have not yet been found for the remainder of the photographs.